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The impact of aeration of concrete based on ceramic aggregate, exposed to high temperatures, on its strength parameters

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HIGHLIGHTS

- It was demonstrated that there is a correlation between aeration and thermal chipping.
- It was proven that 10% aeration reduces considerably thermal chipping phenomenon.
- It was demonstrated that aeration has a favourable impact on compression strength.
- It was proven that ceramic aggregate can be used to concretes resilient to high temp.
- It was demonstrated that aeration has a favourable impact on bending strength.

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ABSTRACT

The modifiers currently being applied enable obtaining cement composites of barely unlimited number of specific features which satisfy the needs of construction market. Due to this fact, it is possible to obtain concretes of increasingly greater strength, frost resistance, in the same time decreasing their absorbability and water permeability. Despite the fact that the concrete is a non-combustible material and considered by a lot of people as resistant to the exposure of high temperatures especially during fire phenomena, there occur many negative processes which weaken its quality and adversely influence strength parameters. From the safety point of view, a particularly hazardous situation concerns the phenomenon of spalling, so-called thermal and explosive chipping of concretes. This particularly refers to damp concretes of compact structure occurring in the places where there are very humid conditions, such as cellars, underground garages, basements or tunnels.

The research, conducted by the authors, has shown that it is possible to obtain porous concrete of high porosity and strength (Zegardło et al., 2016) [1]. These studies have inclined the authors to make an attempt to design the concrete on the basis of ceramic aggregate containing aeration admixtures which is in the same time resilient to high temperatures occurring during the fires, as well as the phenomenon of thermal and explosive chipping.

In this work, the issue of the impact of fire temperatures on concrete is presented as well as the phenomenon of thermal chipping of concrete cladding is discussed. The main aim of this paper is the assessment of concrete aeration effectiveness as the method for reducing the phenomenon of thermal chipping. Concrete samples based on Portland cement and calcium aluminate cement are used for the research simulating thermal activity of fire. The additive of properties described in the further part of this paper, is applied to aerate a concrete mix.

The research is conducted on six, empirically designed concrete mixes, three of which are based on calcium aluminate cement and aeration equal to 0, 5 and 10%. In order to compare the results, three concrete mixes based on Portland cement, which possess precisely convergent aeration of mixes respectively amounting to 0, 5%, 10%, have been prepared. All the types of samples were made with the use of recycled sanitary ceramic aggregates, selected and crushed into two fractions of 0–4 mm and 4–8 mm. This special type of aggregate, as it has been proven by the previous works of authors Halicka and Zegardło (2011) [2], Ogrodnik et al. (2012) [3], Halicka et al. (2013) [4], Zegardło and Ogrodnik (2016) [5], showed very favorable features in the issues of thermal loads impact. The first group of samples is a base one. The second

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part was exposed only to annealing. The others were subjected to moisture, prior to annealing. Basic research was conducted for particular concrete samples. The compression and bending strengths were also determined.

1. Introduction

In the course of concrete designing which is resilient to high temperatures, the most important issue is the proper selection of components. In reference to a binder, a safe temperature to which Portland cement can be applied is 250 °C [5]. Concretes working at higher temperatures than 250 °C are classified as special concretes, and it is assumed that Portland cement shall not be used for their preparation. In this regard, two types of concretes are distinguished, heat resistant ones which are intended for work at increased temperatures (higher than 250 °C) and refractory ones working at high temperatures (even 1000 °C and greater). There is no precise temperature boundary between heat resistance and fire resistance of concretes. There can occur various values, such as 1000 °C [5,7], 1200 °C [6] or even 1500 °C.

While designing concretes resilient to high temperatures, equally significant to the choice of binder is the appropriate selection of aggregate. Its resilience to high temperatures, as in the case of a binder, also primarily depends on its chemical composition. Over the last few years, a new trend in the production of concretes has been to design and create them on the basis of aggregates from recycled ceramic materials. In general, ceramic wastes can be divided into two basic groups in terms of materials they were made of. First part wastes concern the products made of fired red clay such as bricks, ceramic hollow blocks, or roof tiles [8]. The second group refers to production wastes in plants that make products from noble, so-called white clays. Sanitary ceramics, insulators, tableware and Chinese ceramics fall within this category [9,10].

Currently conducted studies related to the use of red ceramics in the form of blocks and ceramic or clinker bricks, concern their application after grinding in the form of fine and coarse aggregate to concrete as a recycling material [11–16]. Other works describe the effect of debris use in the form of ceramics material as an aggregate to concrete [17,18]. The part of researchers also demonstrate the results of studies on ceramics, especially red one, applied to concrete production, focusing on the effect of environmental protection and the decrease in the use of natural resources [19–23]. The research performed by the authors confirmed the possibility of ceramics use as an aggregate for concretes. However, due to different features of crushed red ceramics, strength parameters significantly diverge from each other. The obtained results of research on compression and bending strength of concretes prepared in such a way show unfavorable, almost linear dependency between the content of red ceramic additive and obtained strength values. The greater content of ceramic aggregate, the less strengths.

The analysis of strength studies on concretes composed of aggregate made of sanitary and technical ceramic wastes (sanitary ceramics, electrical ceramic insulators) confirms beneficial impact of the aggregates of this type on concrete strength. Strength parameters of this concrete are close to or even exceed the parameters of concrete based on traditional aggregates in the presented studies [24–29]. Moreover, as it results from the conducted research, this type of aggregate is characterized by the insignificant thermal expansion coefficient oscillating between 0.4 and 0.85·10-5K-1.

In the showed research [29] the authors describe the results of studies on mechanical qualities of concretes in which thicker fractions of aggregate (5–20 mm) have been replaced by the aggregate of sanitary cullet. The compression strength of concretes obtained from these mixes were examined after 14 and 28 days from preparation. It results from the studies that after 28 days the compression strength was greater by 2–8% in comparison to concrete with a traditional aggregate and increased along with the content of ceramic aggregate. In the work [30] the results of concrete studies have been presented, in which the part of sand fraction was replaced by the powder obtained from ceramic cullet. Ceramic powder constituted from 10 to 50% of sand fracture. The research proved that the described additive had a beneficial effect on concrete strength. The studies on samples were carried out after 14 and 28 days from the formation. The greatest strength was achieved by the concrete with the addition of ceramic powder in the amount of 50% of sand fraction and it was greater of about 20% in relation to the concrete without the addition of powder. The authors of works [26,27] used the wastes of white ceramics in the amount of 15–25% as the additive to concrete aggregate. The research results obtained after 28 days showed the strength greater by 2–11% in reference to the concrete made of gravel aggregate. In the own research conducted by the authors [1–5] on the impact of high temperatures on porous and tight concrete based on aggregate produced from ceramic cullet demonstrated a beneficial influence on strength parameters in comparison to the one on a gravel aggregate. During the tests, in the case of tight concrete, the explosive destruction of cubic samples in line with a 'temperature-time' standard curve could be observed while annealing. Considering the limited possibilities of porous concrete applications, there occurred the attempts to design a tight concrete on the basis of aggregate produced from sanitary cullet of high strength which is in the same time resistant to the action of high temperatures and is not subjected to thermal chipping. Using the iterative method for designing a concrete mix and limiting mix substrates to the commonly used cements as well as the proper amount of aerating additive, the tight concrete of high strength parameters was obtained which is simultaneously resistant to explosive chipping of structures.

2. The phenomenon of concrete spalling during a fire

Thermal instability of concrete concerns its behavior in the conditions of high and fast increasing temperature which occurs during a fire. During the fires that occurred in the communication tunnels (under the English Channel – 1996, Mont Blanc – 1999, Gotthard 2001), the loss of concrete cross-section and drop in construction elements capacity were observed due to the explosive nature of concrete (concrete fire spalling) [31–34]. In practice, there are various types of concrete chipping, among others, the so-called popcorn effect when the small parts of concrete chip with accompanying characteristic 'popcorn' sound and explosive behavior while bigger fragments are loosened with great energy [35,31]. The explosive behavior of concrete as a result of high temperature action is, without any doubts, one of the most complex issues in the civil engineering, and due to its practical significance, the series of experimental [36–39] and theoretical [40,41] works was performed which aimed at clarifying the mechanisms and the reasons for the operation of this phenomenon. The explosive spalling of concrete is believed to be the most hazardous type of concrete